AD-A192 085

1

Systems, Science and Software

SSS-R-81-4945

IMPROVED ELEMENTS OF A NETWORK EVALUATION PROGRAM

J. M. Savino

R. C. Goff

W. L. Rodi

FINAL TECHNICAL REPORT

Sponsored by:

DEFENSE ADVANCED RESEARCH PROJECTS AGENCY

ARPA ORDER NO. 3838

This research was supported by the Advanced Research Projects Agency of the Department of Defense under Contract No. MDA903-81-C-AA03

"The views and conclusions contained in this document are those of authors and should not be interpreted as representing the official policies, either expressed or implied, of the Defense Research Projects Agency or the US Government."

S3 Project No. 11160

April 1981

P. O. Box 1620
La Jolla, California
92038
(714) 453-0060

ARPA Order No: 3838

Effective Date of Contract: October 6, 1980

Contract Expiration Date: April 6. 1981

Contract Number: MDA903-81-C-AA03

Principal Investigator and Phone Number:

Dr. John M. Savino, (714) 453-0060, Ext. 453

Project Scientist and Phone Number:

Dr. Ralph W. Alewine, III, (202) 694-3145

Short Title of Work: Improved Elements of a Network Evaluation Program

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER	2. GOVT ACCESSION NO. ADA192085
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle) IMPROVED ELEMENTS OF A NETWORK EVALUATION PROGRAM	5. TYPE OF REPORT & PERIOD COVERED Final Technical Report
	6. PERFORMING ORG. REPORT NUMBER SSS-R-81-4945
7. AUTHOR(s) J. M. Savino, R. C. Goff, W. L. Rodi	8. CONTRACT OR GRANT NUMBER(s) MDA903-81-C-AA03
9. PERFORMING ORGANIZATION NAME AND ADDRESS Systems, Science and Software, P. O. Box 1620, La Jolla, California 92038	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS ARPA Order No. 3838
11. CONTROLLING OFFICE NAME AND ADDRESS Defense Advanced Research Projects Agency, 1400 Wilson Boulevard, Arlington, Virginia 22209	12. REPORT DATE April 1981
	13. NUMBER OF PAGES 11
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	15. SECURITY CLASS. (of this report) Unclassified
	15a. DECLASSIFICATION DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Computer Terminal System
Seismic Network Location Program

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The objective of this project was to provide all personnel, facilities, equipment and management necessary for acquiring and installing at the Project Office a dedicated computer terminal and graphics system. The complete system was installed during March, 1981, and will be used for implementation of a network location program that is being developed for the Defense Advanced Research Projects Agency (DARPA) under a separate contract by Systems, Science and Software (S^3). One of the uses of the computer terminal system will be to

20. Abstract (continued)

display confidence regions of hypocenters for various configurations of globally distributed event source regions and seismic recording stations.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

I. INTRODUCTION

The objective of this project was to provide all personnel, facilities, equipment and management necessary for acquiring and installing at the Project Office a dedicated computer terminal and graphics system. The complete system was installed during March, 1981, and will be used for implementation of a seismic network location program that is being developed for the Defense Advanced Research Projects Agency (DARPA) under a separate contract by Systems, Science and Software (S^3). One of the uses of the computer terminal system will be to display confidence regions of hypocenters for various configurations of globally distributed event source regions and seismic recording stations. (Keywords: algorithms; quantitative approach; worldwide stations).

II. TECHNICAL DISCUSSION

2.1 DESCRIPTION OF EQUIPMENT

During the course of this project, we ordered hardware equipment for a dedicated computer terminal system. The equipment consisted of the following items:

- Two (2) VA 3434 1200 baud acoustic couplers.
- One (1) LA 120BA DECWRITER III 1200 baud terminal, cable, pad and ribbons.
- One (1) Tektronix Data Communications Interface (#021-0074-01) 4010 to Data Com RS232.
- One (1) Tektronix Expanded Symbol and Character Package (#020-0314-02).
- Two (2) 32 k Bytes Tektronix Memory Expansion boards (#020-0288-01).
- One (1) Tektronix Programmable Keyboard (#018-0127-02).
- One (1) Tektronix Power Supply (#040-0844-01), including separate installation.

This equipment was installed at the ARPA Project Office, 1400 Wilson Boulevard, during March 1981. All the equipment was interconnected and checked out during the installation visit by an S^3 staff member. In addition, he made arrangements for a telephone line connection to the main ARPA computer and prepared a write-up on the usage of the terminal. The write-up, which included information necessary for signing onto the system and dialing up the appropriate computer, was left at the Project Office.

The computer terminal system described above will be used for implementation of network location programs that were developed for DARPA at S^3 under a separate contract (MDA 903-79-C-0670). Algorithms developed under this separate contract will be tested for computing expected location errors for a specified seismic event recorded at a specified network of seismographic stations. The terminal system can be used to display confidence regions for various configurations of event source regions and globally distributed seismic stations.

2.2 DESCRIPTION OF NETWORK EVALUATION ALGORITHM

An important element in the evaluation of a seismic network for nuclear monitoring is measuring the network's capability for event location. Described here is an algorithm, based on linear inverse theory, for predicting the location capability of a real or hypothetical network and determining the importance of individual data observed by the network. The data may include the arrival times of regional and teleseismic P and S phases, including pP, and backazimuth estimates derived from Lg. The data importances allow one to rank stations or phases by the information they contribute to the network, and thus are a valuable guide in the design of improved networks.

2.2.1 Method

The network evaluation algorithm is a multiphase extension of an earlier algorithm developed by M. H. Wirth (1970). The new algorithm assumes a linear inverse formulation of the event location problem. An optimal estimate of the four-vector of location parameters (epicentral coordinates, focal depth and origin time) is defined as the minimum-variance linear estimate derived simultaneously from all the network data The 4 by 4 parameter covariance matrix of the estimate can be determined knowing only the variances of the data errors and the partial derivatives of the data with respect to the location parameters. By assuming a probability distribution for the data errors (Gaussian), the parameter covariance matrix can be expressed as a four-dimensional confidence region for the location estimate.

Instead of using the four-dimensional confidence region, the algorithm measures the location capability of a network in terms of separate confidence regions determined for the epicentral coordinates and focal depth. These are obtained from the marginal variances of the separate parameter estimates; therefore, they reflect trade-offs between all four of the location parameters (i.e., none of the parameters is assumed to be known or fixed). The distinction between network capabilities for epicenter and depth determination is important in nuclear monitoring problems.

In practice, the location capability of a network is degraded by the absence of data from undetected phases at some stations. This source of uncertainty in network location estimates is described by detection probabilities assigned to the phases at each station. The detection probabilities depend on the event magnitude as well as its true location. The effect of the detection probabilities P_i on the expected average network performance can be treated approximately in the linear inverse formulation by increasing the variance of each datum by the factor P_i^{-1}.

The algorithm for data importances is based on concepts developed by Minster, et al. (1974). For a given event, two importances are calculated for each network datum: its importance for determining the event epicenter and its importance for determining the focal depth. They are defined by the increase in the size of the confidence regions that would result by omitting the datum from the data set and locating the event with the remaining data. Denoting the area of the epicenter confidence ellipse as E and the length of the depth confidence interval as d, the importances of the i'th datum are defined by

$$\text{Epicenter Importance} = \frac{E\ (\text{without i'th datum})}{E\ (\text{with i'th datum})}$$

$$\text{Depth Importance} = \frac{d\ (\text{without i'th datum})}{d\ (\text{with i'th datum})}\ .$$

The importances take values between one and infinity, and larger values imply more important data.

Importances can be computed directly from the full network data variances and the partial derivative matrix A, or equivalently, from the eigenvalues and eigenvectors of A. It is not necessary to repeat confidence region calculations with each datum dropped in turn. The importances defined here are, in fact, related to the information density matrix S (Wiggins, 1972), which is obtained from the column eigenvectors of A. The diagonal elements of S measure the first-order sensitivity of the confidence regions to the data variances.

2.2.2 Examples

Figures 1 through 3 give examples of ranking stations in a network based on their importances for determining the epicenter and depth of an event. In each example, it is assumed that only the first motion P wave arrival time is determined at each station. Thus, the data importances directly reflect the importances of the stations themselves. At each station the probability of detecting the P wave is assumed to be one and the arrival-time standard error to be 1.0 second. Therefore, in these examples, the depth and epicenter importances of a station depend on the station's location relative to the event and the other stations in the network, rather than on data quality.

Figure 1 ranks the stations in each of three hypothetical networks distributed in simple patterns about an event. Each network is shown twice to give the station ranking by epicenter importance and depth importance. The ranks are plotted at the station locations and they are assigned in order of decreasing importance (Station 1 is the most important in the network). Because of the symmetry in the networks, two stations often have equal importances and rank. One should note that the importance values themselves are not shown and the rank defines only an ordering of the stations by importance.

The networks in Figure 1 each have six stations at three epicentral distances from the event ($\Delta = 20°, 40°, 60°$), but they differ in their azimuthal distributions. Network 1 provides the best, and Network 3 the worst, azimuthal coverage. As a result, the epicenter confidence ellipse (not shown) is largest for Network 3 and smallest for Network 1. The

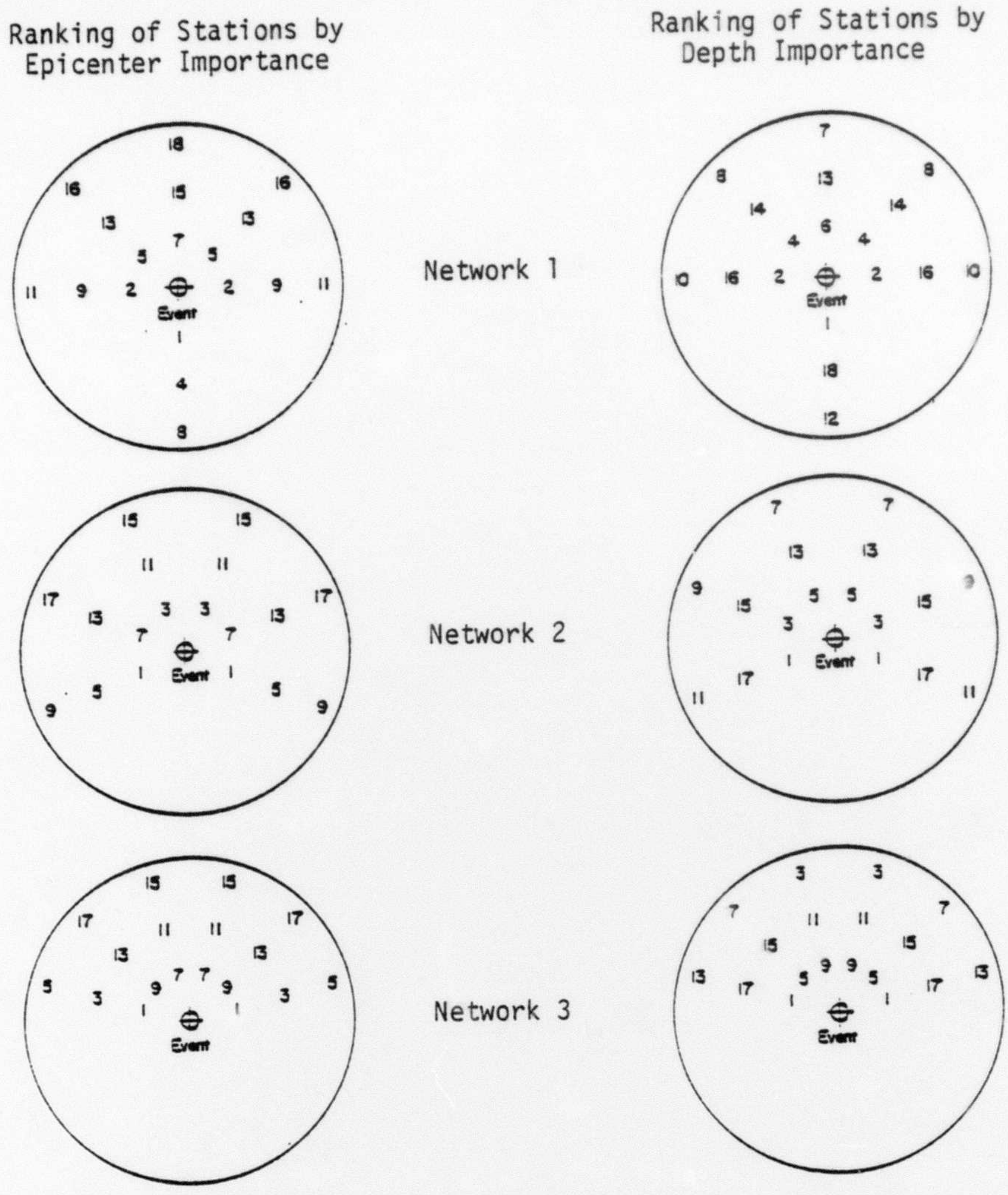

Figure 1. The stations within each of three simple networks are ranked by their importances for determining the epicenter and focal depth of an event based on P wave arrival times. The networks each have 18 stations distributed at three distances from the event ($\Delta = 20°$, $40°$, and $60°$) but the azimuthal distributions of the networks differ. The rank of a station is plotted at the station location (1 for the most important station in the network, 2 for the second most important station, etc.).

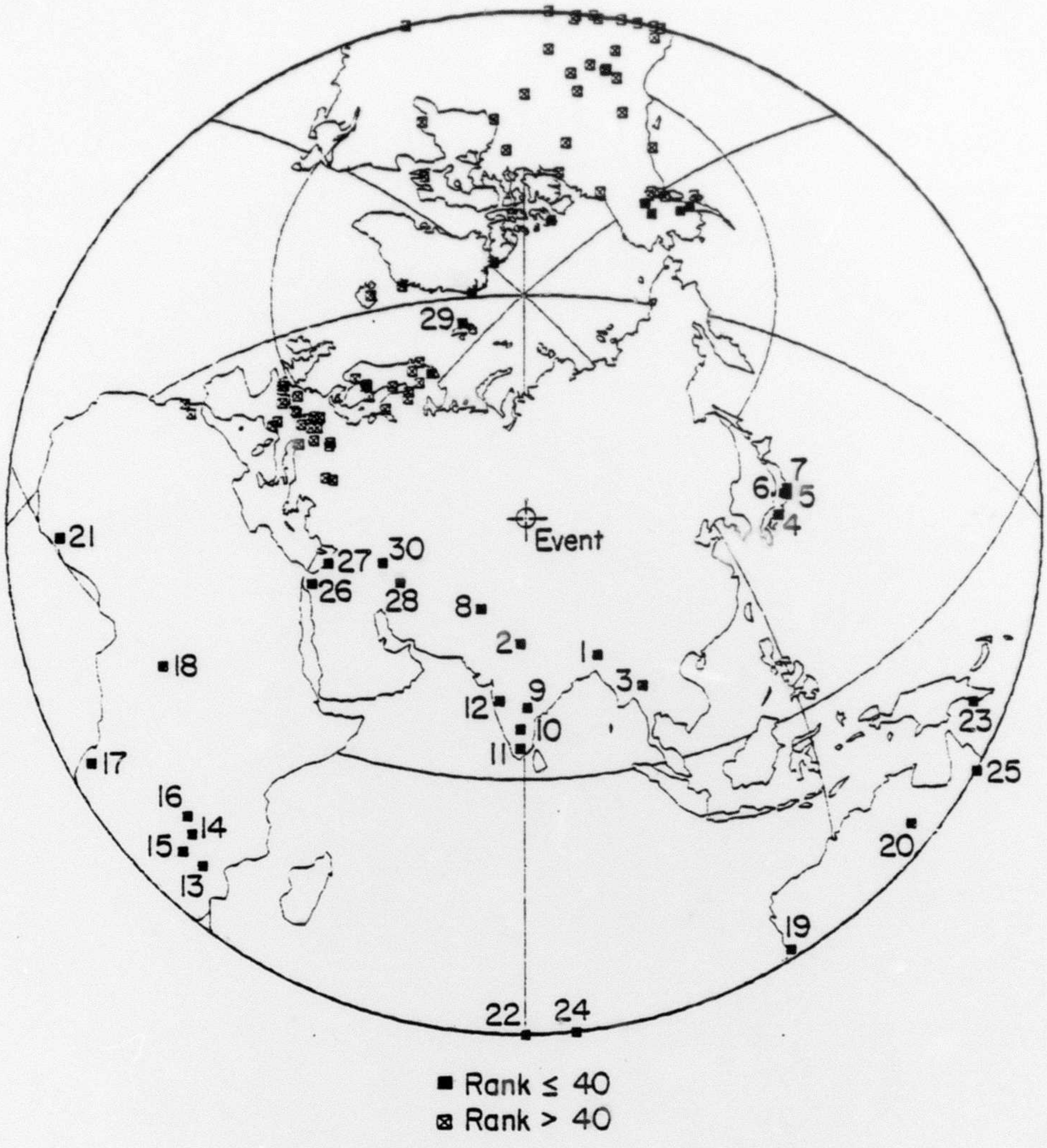

Figure 2. Ranking of 113 worldwide stations by their importance for locating the epicenter of an event (⌖) in Eurasia. The 40 most important stations are plotted as solid squares and the ranks of the 30 most important stations are indicated. Stations at epicentral distances greater than 90° are plotted on the circumference of the plot (Δ = 90°).

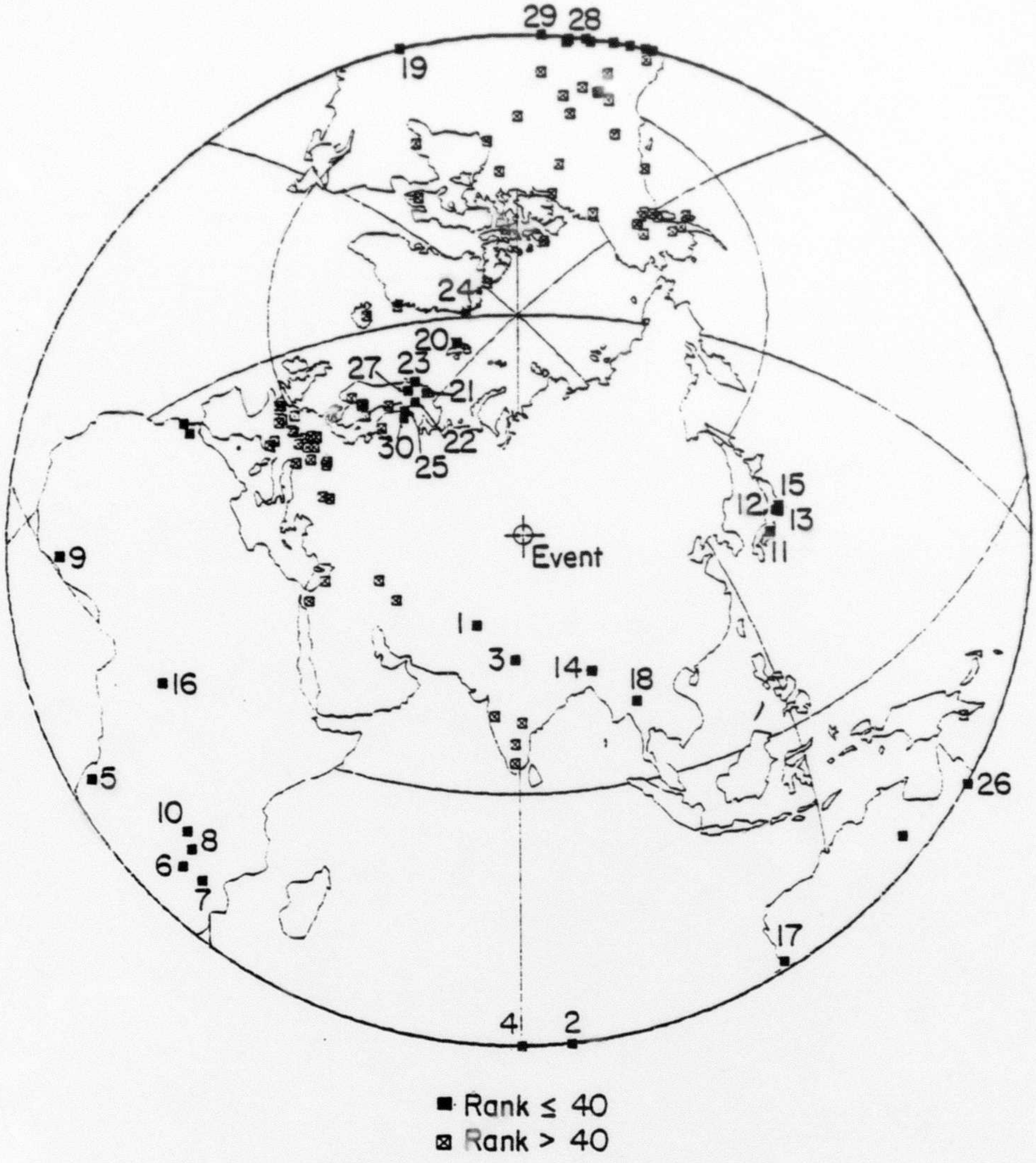

Figure 3. Ranking of 113 worldwide stations by their importance for determining the focal depth of an event in Eurasia. The 40 most important stations are plotted as solid squares and the ranks of the 30 most important stations are indicated. Stations at epicentral distances greater than 90° are plotted on the circumference of the plot (Δ = 90°).

networks determine very nearly equal focal depth confidence intervals, however, since depth determination depends primarily on distance coverage rather than azimuthal coverage.

The importance rankings shown in Figure 1 display clearly the influence of station location on station importance. For epicenter determination, the stations closest to the event and those near any gaps in azimuthal coverage are the most important stations in a network. In Network 3, one can see that when a large gap in azimuthal coverage occurs, proximity to the gap overrides epicentral closeness in controlling the importance of a station. The depth importance rankings show a different effect. The stations closest to the event and farthest from the event are the most important for determining focal depth. Stations at intermediate epicentral distances, compared to the distance range spanned by the network, are least important. Furthermore, station azimuth is not a critical factor for determining focal depth from P arrival times.

Figures 2 and 3 show the importance rankings of actual worldwide stations for locating an event in Eurasia. The 113 stations in this network were selected as follows. Three events with similar magnitudes ($m_b \simeq 5$) and nearly identical locations were selected from the 1969-1970 Bulletins of the International Seismological Centre (ISC). Stations reporting P arrivals from one or more of these events were included in the network for this example. While this criterion defines a representative network of stations operating in 1969-1970, it should be noted that considerably fewer stations typically report a single $m_b = 5$ central Asian event (≤ 65 for the three events chosen). Furthermore, in this example the stations were treated as equal in quality, although many reported only one or two of the events or reported emergent P arrivals. Therefore, this example serves mainly to illustrate the effects of worldwide station geometry rather than to evaluate the true capability of worldwide stations for locating $m_b = 5$ Eurasian events.

In Figures 2 and 3, the 40 highest ranking stations are shown as solid squares and the rest as open squares with crosses. The ranks of the 30 most important stations are labeled. The rankings display a dependence on station distribution imilar to that of the hypothetical networks. The stations ranking highest in epicenter importance (Figure 2) are generally either at the closest epicentral distances (e.g., southern Asia) or in sparsely covered azimuthal ranges (e.g., Japan and South America). Stations at both long and short epicentral distances rank high in importance for determining event depth (Figure 3).

The variation in station density in this example (Figures 2 and 3) complicates the relationship between station importance and station distribution, an effect that was not a factor in earlier examples. Stations in a cluster tend to have small importances individually, although as a group their joint importance may be quite large. The European and Fennoscandian stations in Figure 2 are the best example of this. They are fairly close to the event and cover an otherwise azimuthal range, but due to their number and dense spacing each individual station is relatively unimportant for determining the event epicenter.

2.2.3 Conclusions

The examples presented here are rather simple applications of the network evaluation algorithm. Only P wave data were used and detection probabilities and station quality were not taken into account. Moreover, the method at this time does not fully account for biases in arrival-time data caused by path anomalies, which are known to be a significant source of error in event locations. Nonetheless, the examples demonstrate that this quantitative approach to measuring network and station performance for event location is a useful tool for the design of improved networks, and also for acquiring a better understanding of location techniques.

III. REFERENCES

Minster, J. B., T. H. Jordan, P. Molnar and E. Haines (1974), "Numerical Modeling of Instantaneous Plate Tectonics," Geophys. J. R. astr. Soc., 36, pp. 541-576.

Wiggins, R. A. (1972), "The General Linear Inverse Problem: Implication of Surface Waves and Free Oscillations for Earth Structure," Rev. Geophys., 10, pp. 251-285

Wirth, M. H. (1970), "Estimation of Network Detection and Location Capability," Research Memorandum, Air Force Technical Applications Center, August (Revised October 1977 by R. Blandford and H. Husted).